EXHIBIT 17

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Computer Applications

Assessment of Visually Lossless Irreversible Image Compression: Comparison of Three Methods by Using an Image-Comparison Workstation[1]

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Abstract

PURPOSE: To determine the degree of irreversible image compression detectable in conservative viewing conditions.

MATERIALS AND METHODS: An image-comparison workstation, which alternately displayed two registered and magnified versions of an image, was used to study observer detection of image degradation introduced by irreversible compression. Five observers evaluated 20 16-bit posteroanterior digital chest radiographs compressed with Joint Photographic Experts Group (JPEG) or wavelet-based trellis-coded quantization (WTCQ) algorithms at compression ratios of 8:1–128:1 and x2 magnification by using (*a*) traditional two-alternative forced choice; (*b*) original-revealed two-alternative forced choice, in which the noncompressed image is identified to the observer; and (*c*) a resolution-metric method of matching test images to degraded reference images.

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RESULTS: The visually lossless threshold was between 8:1 and 16:1 for four observers. JPEG compression resulted in performance as good as that with WTCQ compression at these ratios. The original-revealed forced-choice method was faster and as sensitive as the two-alternative forced-choice method. The resolution-metric results were robust and provided information on performance above visually lossless levels.

CONCLUSION: The image-comparison workstation is a versatile tool for comparative assessment of image quality. At x2 magnification, images compressed with either JPEG or WTCQ algorithms were indistinguishable from unaltered original images for most observers at compression ratios between 8:1 and 16:1, indicating that 10:1 compression is acceptable for primary image interpretation.

Index terms: Computers, diagnostic aid • Data compression • Images, artifact, **.93, **.99[2] • Images, display, **.1215, **.99[2] • Images, processing, **.99[2] • Picture archiving and communication system (PACS)

Introduction

For the past 2 decades, many researchers in radiology have predicted the replacement of hard copy–based, manually administered, diagnostic imaging operations by electronic picture archiving and communication systems (PACS). Re-engineering of radiology operations with PACS can dramatically improve health care delivery by enabling rapid distribution of images and information, improving resource utilization, and providing better service to caregivers (1,2). Although advances in technology have allowed successful demonstration of this concept, the high cost of systems (3) and the low comfort level of health care delivered with new and unfamiliar techniques has impeded widespread deployment. An important factor in the cost of PACS is the large amount of information contained in radiologic images, which results in terabytes of data that must be managed and distributed (1,2). The requirements for storage devices and networks thus constitute a substantial investment and ongoing costs to achieve the benefits of PACS.

Data compression, a technology that reduces the size of image files, provides immediate and substantial reduction in the cost of PACS deployment. Image compression techniques are designed to reduce data redundancy by means of special image coding and, as a result, can greatly reduce the effective amount of image data and, therefore, the volume of storage or transmission time required per image. Mathematically lossless compression techniques (compression and reconstruction with no loss of original data) result in compression factors on the order of 2:1 to 3:1 for radiologic images, which are insufficient to produce adequate reductions in transmission time or storage costs. To achieve these goals, compression factors on the order of 10:1 or higher are required, which implies that irreversible or lossy compression must be used; that is, some

information must be lost in the compression and reconstruction process. However, some loss of image data can be tolerated without affecting the visual interpretation of an image (4).

A major challenge in the adoption of lossy image compression in the medical community is to develop a body of research that supports the use of fewer data than are included in the full image for primary diagnostic interpretation. The characteristics of the human visual system are such that an image reconstructed after irreversible compression may appear indistinguishable from the original, and, thus, the compression is "visually lossless" (5). We believe that under these circumstances, the image is therefore diagnostically lossless; that is, image compression will have no effect on diagnostic interpretation. The purpose of our investigation was to compare three methods for the evaluation of compression artifacts by using a workstation designed to increase observer sensitivity to subtle differences, thereby arriving at a conservative and, we hope, widely accepted estimate of the visually lossless threshold. Image quality assessed by evaluating observers' perception of degradation as a function of compression ratio was the primary focus of our investigation.

MATERIALS AND METHODS

Image Comparison Workstation

The image comparison workstation (ICW) was developed as a collaborative project between the Electronic Radiology Laboratory at our institution and the Health Imaging Research Laboratory of Eastman Kodak (Rochester, NY). The goal was to construct a workstation and software that would allow rapid processing and presentation of images on high-resolution (2,000 x 2,500-pixel) monitors. The ICW was designed specifically for the study of performance with lossy image compression techniques (6).

The workstation consisted of a personal computer (Kayak XU6/300; Hewlett Packard, Palo Alto, Calif) equipped with dual 300-MHz Pentium II processors (Intel, Santa Clara, Calif), a 9-Gbyte RAID (redundant array of inexpensive disks) disk array, and 512 Mbytes of random access memory), with model P1540 display cards (Metheus, Beaverton, Ore) driving a 21-inch-diagonal (53.3-cm-diagonal), 2,048 x 2,560–pixel, low-spatial-noise phosphor (P45), 71-Hz monitor (model DR 110; Data Ray, Westminister, Colo) with a maximum luminance of 220 candelas per square meter (luminance dynamic range of 650:1). The software application, which is implemented for the Windows NT operating system (Microsoft, Redmond, Wash), was developed by the Health Imaging Research Laboratory (Eastman Kodak). The user interface is shown in Figure 1.

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Figure 1. Direct screen capture shows the ICW graphical user interface. A small replication of the entire image is shown in

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the lower left-hand corner, where the white box defines the portion of the image displayed in the top 80% (2,048 x 2,048 pixels) of the monitor. The set of resolution images for comparison is listed in the box on the right for test case 18-5. The "Prev" and "Next" buttons in the "Test Image" area change the test image being compared. The "Prev" and "Next" buttons in the "Control Image" area change the resolution reference image. This can also be changed by using the wheel on the mouse or the up and down arrows in the "Best Match" area. The "Flicker" area offers selection of "Auto" or "Manual" for automatic or manual control of flicker, respectively, and a slider to set the flicker rate in the automatic control mode. The "Zoom In" area offers a choice of x1, x2, or x4 magnification. The x2 magnification is displayed in this example. The "Mark as Best" button records the control image selected as the best match to the test case. A warning is displayed if the user tries to move to the next case without recording a choice.

The approach used in this study was to compare two versions of an image on a single monitor by using an interactive soft-copy feature. Inherent in the design was the use of "flicker," which is defined as sequential display of two registered images on the same monitor. This method was used to exploit the observer's temporal sensitivity to differences in the image, because the human visual system is naturally drawn to changes in structure or brightness. This technique allows detection of subtle differences and provides a mechanism for comparing image quality loss caused by different kinds of distortion. The observer has direct control of flicker and can set it to automatically change images at up to five times per second; alternatively, the user can use a manual mode, which allows the observer to selectively toggle between the two images, as desired.

The current software allowed x1 magnification to simulate clinical application, while x2 and x4 magnifications were available to help improve detection of subtle differences. A small representation of the entire image with the area chosen for magnification was displayed in the lower left-hand corner of the monitor. The portion of the image displayed for evaluation occupied the upper 80% of the screen, as shown in Figure 1, and measured 30 x 30 cm. The observer could change the region of the image displayed by panning with the mouse on the image representation in the lower left-hand corner. Thus when x2 or x4 magnification was used, the observer was free to study any desired segment of the full image. A wide assortment of information could be recorded automatically by the computer as an observer worked through an experiment to compare a series of images and to make choices.

Images

The image set used in this study consisted of 20 digital posteroanterior chest radiographs obtained from the outpatient admitting area at our institution. A commercial selenium detector system (Thoravision; Philips Medical Systems, Shelton, Conn) was used to obtain the images. Images normally have an addressable area of 2,048 x 2,560 pixels with a pixel size of 0.2 mm. The use of

digital chest images in the context of primary interpretation is well supported by research results (7–9) on radiologists' preference and performance as assessed with receiver operating characteristic analysis for comparison with state-of-the-art, wide-latitude, dual screen-film images. The images selected for this investigation included studies in men and women with pneumonia, pulmonary nodules, interstitial lung disease, mediastinal masses, catheters, or implanted hardware.

Image Compression

There are many compression techniques available and much research on algorithm improvement (10,11); however, interoperability is crucial to a successful PACS, so we have focused our efforts on existing standards defined by the Joint Photographic Experts Group (JPEG) (12). JPEG baseline is the most widely available block discrete cosine transform algorithm. Advantages include wide availability, interoperability with other JPEG-compliant encoding and decoding software, reasonably fast "run times," and widespread vendor support. It is the only compression algorithm sufficiently documented to be proposed by the National Electrical Manufacturers Association (13) as a standard for Digital Imaging and Communications in Medicine, or DICOM.

Other important methods to investigate are wavelet-compression techniques, because these techniques have special features and functionality (14–16). Driven by broad interest, the JPEG 2000 Committee was established to formulate a new standard, ostensibly to be based on wavelet compression. We thus included the wavelet-based trellis-coded quantization (WTCQ) algorithm developed at the University of Arizona as a representative example of this class of algorithm (17).

The original radiograph (postprocessed, relative log luminance data) was retrieved from an optical disk and linearly transformed from a 0–30,000 scale to a 0–4,095 scale to match the 12-bit requirements of the compression algorithms. The image compression rates were selected on the basis of pilot data and corresponded to 2.00, 1.50, 1.00, 0.75, 0.50, 0.25, and 0.125 bits per pixel. Because the original image was created with 2 bytes per pixel, as is typical for most commercial digital radiographic systems wherein "byte-packing" is not used, we calculated, for the convenience of the reader, a compression ratio defined as 16 bits divided by the number of compressed bits per pixel. Representative examples are shown in Figure 2.

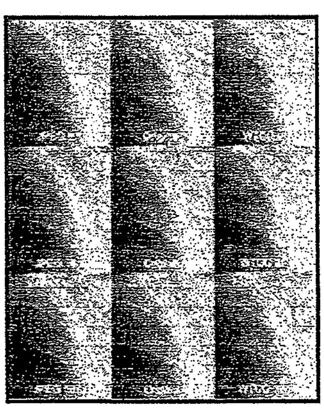

Figure 2. Compression artifacts. Compressed (JPEG, left column; WTCQ, right column) and noncompressed digital (middle column) posteroanterior radiographs of a selected region of interest show the effects of compression at ratios of 8:1 (top row), 16:1 (middle row), and 128:1 (bottom row). With both JPEG and WTCQ algorithms, the image compressed at 8:1 is indistinguishable from the original. At a compression ratio of 128:1, the manifestation of "tiling" or "blocking" artifacts on the JPEG image and blurring on the WTCQ image are readily apparent.

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Observers
The five independent observers included two imaging scientists (B.R.W., E.M.) with extensive experience in image processing and display and three board-certified radiologists, including specialists in chest (R.M.S.), musculoskeletal (D.A.R.), and general (P.H.) radiology. The introductory training session for each observer included a discussion of the purpose and objectives of the evaluation, a description of the protocol, and an online walk-through of the evaluation procedure and operation of the ICW.

Image Evaluation Methods
Three methods were chosen for image comparison and evaluation. All three were conducted by using the ICW at x2 magnification, which allowed 25% of the total image area to be viewed at a time. Although it is possible to pan (roam) and view the entire image, observers limited their observations to the upper right-hand quadrant of each image for this study.

Twenty test "folders" (computer directories) were prepared and randomized for each reader. Each folder used a different image and contained 16 randomized image replicates, including two unaltered original radiographs and images compressed with each of the seven ratios for the two compression algorithms. The order in which the five observers performed the three experiments was random. The amount of time needed for each reading session, reader confidence for each decision, and representative reading distances were manually recorded.

Two-alternative forced choice.—The 16 test images in each folder were paired with a control image (unaltered original) and were presented sequentially without identification (one pair at a time), with the observer toggling between them in a rapid fashion. The observer was asked to choose the image with "better quality" and was forced to choose even if the observer perceived no difference between the images. The observer was asked to record both the image selected and the decision confidence by using a three point scale: score of 0, uncertain or guessing; score of 1, confident; score of 2, very confident. No reader feedback was provided.With this method, a visually lossless level was indicated when responses were evenly divided between test and control images or matched the score distribution for the original-original image pair.

Original-revealed forced choice.—The same 20 test folders were used to conduct a modified two-alternative forced-choice experiment. As in the traditional forced-choice method, each test image was paired with an unaltered original and was presented sequentially (one pair at a time) on the ICW, with the observer toggling between them. The difference between this task and two-alternative forced choice was that the original image was identified for the reader. The observer was asked to compare the test image to the original and decide if the images were equivalent or if there was visible artifact, loss of fidelity, or degradation in the quality of the test image. The

observer knew that sometimes two originals would be shown. We refer to this method as the original-revealed forced-choice method. In an investigation of the human visual system, Gur et al (18) advocate comparison of test images with a known original image to maximize sensitivity to distortion. With this method, a visually lossless level was indicated when the percentage of test images rated as equivalent approximated 100% or matched the score distribution for the original-original image pairs.

Spatial resolution metric.—In this experiment, a test image that had been prepared by applying the compression algorithm was compared to a set of reference images that had been prepared by degrading the image in a controlled manner. A set of 15 reference images was prepared for each test image by using "blur" as the metric. Blur was introduced by degrading the spatial resolution of the image while maintaining image size. This bandwidth reduction was performed by transforming the image into the frequency domain, applying a set of 14 power-law filters, then "back-transforming" the filtered data into the spatial domain. Power-law filters were selected to provide rectangular bandpass characteristics in the frequency domain while producing minimal distortion in the spatial domain (6).

Because the image is two-dimensional while the filters are separable (one-dimensional), the square of the bandwidth reduction can be used as a measure of two-dimensional spatial resolution. Figure 3 shows the full range of grades of spatial filtration applied to a representative image. For example, a bandwidth reduction factor of 1.25 (grade 4), which corresponded to a 20% reduction in bandwidth, can be thought of as displaying 80% of the original pixels, which were then magnified to the full display size, resulting in a spatial resolution of 64%. This would be analogous to displaying a 2,048 x 2,048-pixel image on a 1,600 x 1,600-pixel monitor. Similarly, a bandwidth reduction factor of 2 (grade 7) corresponded to displaying half the pixels, or 25% resolution, and was analogous to displaying a 2,048 x 2,048-pixel image on a 1,024 x 1,024-pixel monitor.

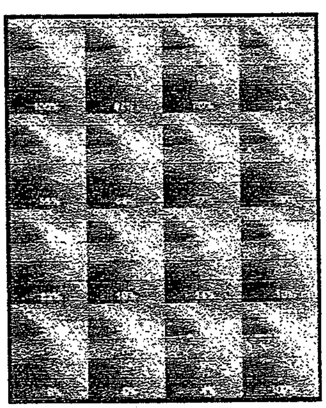

Figure 3. Resolution metric. Composite image shows the spatial-resolution scale applied to a representative portion of a radiograph. Reduction in resolution progresses from grade 1 (top left and bottom right: unaltered original, *100%*) to grade 15 (bottom row, second from right: *4%*). The percentages are a measure of two-dimensional spatial resolution, which was determined on the basis of the square of the bandwidth reduction implemented with power-law filters and can be thought of as the percentage of pixels displayed.

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The test and reference images were presented sequentially for comparison at the ICW, with the observer toggling between them in a rapid fashion. The observer changed the comparison image by using the wheel on the mouse to select from the set of 15 reference images. The observer selected the reference image that most closely matched the test image in terms of clinical utility.

Data Analysis

Data took the form of reader decisions: For two-alternative forced-choice experiments, observers decided which of the two images appeared to be superior; for original-revealed forced-choice experiments, observers decided if an image was equivalent to the original or degraded; for resolution-metric tests, observers decided which level of blurring most closely matched, with respect to clinical utility, the level of compression. Analysis took the form of calculation of the proportion of decisions in a given category, with 95% confidence limits (19). Time needed to complete image comparison and reading distance were evaluated by comparing means.

RESULTS

When making comparisons, observers reported that their focus of attention included structural detail, particularly bone edges and trabecular patterns, and areas of uniform opacity such as the soft tissues of the chest wall. Observers differed in their ability to detect degraded images, but when results from all observers were combined, a fairly clear pattern was found. The mean results for two-alternative forced-choice, original-revealed forced-choice, and spatial resolution–metric experiments for all cases and observers are shown in Table 1. Individual results are shown in Table 2.

View this table: [in this window] [in a new window] TABLE 1. Combined Results for All Observers and Methods

View this table: [in this window] [in a new window] TABLE 2. Visually Lossless Threshold Estimates for Individual Observers

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Two-Alternative Forced Choice

The overall results for the two-alternative forced-choice experiments are presented in Figure 4. When presented with images that were indistinguishable, observers guessed, which resulted in a chance, or approximately 50:50, distribution. As part of the two-alternative forced-choice

experiment, observers were presented with 40 pairs of original images, one denoted as the "test" image and one as the "control" image. The overall response rate for selecting the test or control image as the better image (when in fact both were identical) was 47% or 53%, respectively.

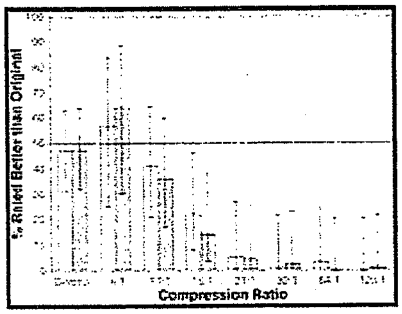

Figure 4. Bar graph shows the combined results for five observers in the two-alternative forced-choice experiments, with the percentage of test images judged to be superior to the original image. The horizontal line at 50% represents the expected result for a purely random selection. Error bars = 95% CIs, gray bars = WTCQ images, white bars = JPEG images.

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The mean responses for images compressed at 8:1 and 11:1 with both algorithms fall within the 95% CIs of the responses for the original images. The 8:1 compressed images were selected as the better image slightly more often than the original for both JPEG (57%) and WTCQ (65%) images. The responses for both JPEG and WTCQ images compressed at 11:1 indicate a slight tendency for observers to select the original image as the better image. The responses for images at 16:1 compression indicate that observers differentiated WTCQ images from original images more frequently than they differentiated JPEG images and that the visually lossless compression threshold was crossed for both. At compression ratios of 21:1 and higher, observers consistently (more than 95% of the time) chose the original as the better image, which indicates that the compression artifact was clearly evident.

These results are supported by the mean confidence scores for two-alternative forced-choice experiments (Table 1). Observer confidence was low (mean score of 0.2) when the choice was between images in an original-original pair and remained low with 8:1 and 11:1 compressed images. Observer confidence increased (mean score > 1.0) when evaluating images compressed at 16:1 and became substantially higher (mean score > 1.7) at compression ratios of 21:1 and higher.

Individual observers trends varied, as shown in Table 2. With JPEG images, the 8:1 compression images were indistinguishable from the original images for four observers, and the 11:1 compression images were indistinguishable for three observers. Observer C, who also had the closest mean viewing distance (as close as 8 cm), noted degradation in all compressed images except for a few compressed at 8:1. Although observer C noted no structural degradation, he noted a change in some individual pixels. With WTCQ compression, the pattern for all five observers was similar and suggested the presence of a visually lossless threshold at x2 magnification for

observers.

Original-revealed Forced Choice
In this experimental design, the observer was presented with an original image and was asked if the test image was indistinguishable or if there was any visible artifact, degradation, or loss of fidelity. Observers were told that there were several unaltered original images included with the test images. When presented with a pair of original images, the observer declared the images to be indistinguishable 95% of the time. The composite results for all observers are shown in Figure 5. As with the two-alternative forced-choice results, the greatest change in performance was found between 11:1 and 16:1 compression for both JPEG and WTCQ algorithms.

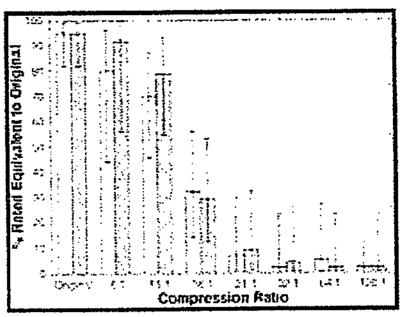

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Figure 5. Bar graph shows the combined results for five observers in the original-revealed forced-choice experiments, with the percentage of test images classified as equivalent to an original image. Error bars = 95% CIs, gray bars = WTCQ images, white bars = JPEG images.

Review of the individual results showed a tendency for two observers to detect degradation in about half of the WTCQ images compressed at 11:1 and a clear trend for four observers to detect degradation in such images compressed at a ratio higher than 16:1. For JPEG images, a larger percentage of images were considered to be degraded at a given compression ratio overall, but this was due primarily to the results of observer C, who detected a difference in all compressed images except for a few compressed at 8:1. Of the other four observers, one detected degradation in about half the JPEG images compressed at 11:1, but none detected degradation in images compressed at 8:1. The mean percentages for these four observers were 94% for JPEG images compressed at 8:1 and 90% for images compressed at 11:1—in both cases, close to the 95% rate found for original-original pairs. At compression ratios of 21:1 and higher with either JPEG or WTCQ, the degradation was detected over half the time by four of the observers.

Spatial Resolution Metric
Fifteen reference images with controlled degradation were available for comparison with each test image, including grade 1 degradation (ie, an unaltered original image). Although observers were able to score intermediate grades, this seldom occurred, which suggests that the existing choices offered were sufficient. Observers reported the ability to consistently select a reference image that matched the degradation in the compressed image, although this was easier with WTCQ images

than with JPEG images at high compression ratios.

The original images were matched with grade 1 images (unaltered original) on the resolution scale 96% of the time; with grade 2, 3% of the time; and with grade 3, 1% of the time. At a compression ratio of 8:1, JPEG images were matched with grade 1 images 94% of the time; with grade 2 images, 5% of the time; and with grade 3, 1% of the time. At a ratio of 11:1, JPEG images were matched with grade 1 images 71% of the time; with grade 2 images, 15% of the time; with grade 3 images, 11% of the time; and with grade 4–6 images, 1% of the time each. At a compression ratio of 8:1, WTCQ images were matched with grade 1 images 96% of the time; with grade 2 images, 3% of the time; and with grade 4 images, 1% of the time. At a compression ratio of 11:1, WTCQ images were matched with grade 1 images 67% of the time; with grade 2 images, 8% of the time; with grade 3 images, 13% of the time; and with grades 4–6 images, 3% of the time each.

The mean percentage resolution matched with each level of compression for the two algorithms is shown in Table 1. There was a progressive decrease in resolution as the compression level increased. As with the two-alternative forced-choice and original-revealed forced-choice experiments, the greatest initial change for both algorithms occurred between compression ratios of 11:1 and 16:1. Although the data were not highly precise, at low compression levels JPEG images were matched with a higher resolution than were WTCQ images, whereas the opposite occurred for the highest compression ratios.

The relationship between compression and resolution was further assessed by plotting the data for JPEG images (Fig 6a) and WTCQ images (Fig 6b). Transformation of the data onto a log scale provided a distribution suitable for linear regression. The log of the compression ratio was plotted on the x axis. In this format, 1.0 corresponded to a compression ratio of 10:1; 1.2, to a compression ratio of 16:1; and so forth. The log of the reciprocal of the percentage spatial resolution was plotted on the y axis and ranged from 0 for the unaltered original to 1.4 for the bandwidth reduction factor of 5.0 (4% resolution). Linear regression was used to calculate the line of best fit. The x intercept was a predictor of the visually lossless threshold. This method was used to calculate the expected visually lossless threshold for each observer by using data for compression ratios higher than the visually lossless level, namely, 16:1 and higher. The calculated threshold and r^2 value for the linear regression fit to the data are shown in Table 2 for each reader and both algorithms.

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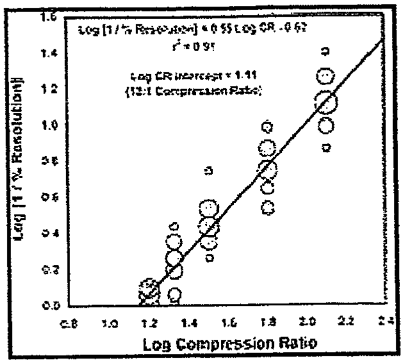
Figure 6a. Resolution-metric matching with **(a)** JPEG images and **(b)** WTCQ images. Scatterplots show the relationship between compression ratio (*CR*) and percentage resolution for observer A. These data were obtained by matching the blur image set with 20 test images at each of five compression ratios (16:1, 21:1, 32:1, 64:1, and 128:1). The area of each dot is proportional to the number of superimposed data points. The straight lines are the regression lines. **(a)** The x



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intercept for JPEG images, determined by means of linear regression on the 100 data points, indicates that the estimated visually lossless threshold is 13:1. **(b)** The x-intercept for WTCQ images, determined by means of linear regression on the 100 data points, indicates that the visually lossless threshold is 11:1.

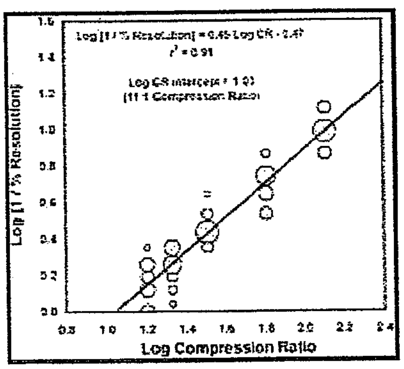

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Figure 6b. Resolution-metric matching with **(a)** JPEG images and **(b)** WTCQ images. Scatterplots show the relationship between compression ratio (*CR*) and percentage resolution for observer A. These data were obtained by matching the blur image set with 20 test images at each of five compression ratios (16:1, 21:1, 32:1, 64:1, and 128:1). The area of each dot is proportional to the number of superimposed data points. The straight lines are the regression lines. **(a)** The x intercept for JPEG images, determined by means of linear regression on the 100 data points, indicates that the estimated visually lossless threshold is 13:1. **(b)** The x-intercept for WTCQ images, determined by means of linear regression on the 100 data points, indicates that the visually lossless threshold is 11:1.

Linear regression also was performed for each observer with systematic elimination of one compression level and again with only the 16:1, 32:1, and 64:1 data. These data manipulations had almost no effect on the x intercept. The mean visually lossless compression ratio was 12:1 for JPEG images and 11:1 for WTCQ images, in all cases.

Viewing Distance and Reading Time

Viewing distance and reading time varied among observers (Table 2). The resolution-metric task required the greatest time commitment, taking about twice as long to complete as the two-alternative forced-choice task. The original-revealed forced-choice task was the quickest method, taking, on average, 25% less time than the two-alternative forced-choice task.

Four observers wore prescription eyeglasses, and one (observer D) wore nonprescription reading glasses. Observer C positioned himself much closer to the images than did the other four observers. This observer was very nearsighted and, with prescription lenses, was able to focus

much closer than the typical viewer. We have already noted the differences in some of the results of observer C.

DISCUSSION

Reversible, or mathematically lossless, image compression provides an inadequate reduction in the amount of data to provide substantial engineering advantages or cost reductions for image transmission or storage. Irreversible, or lossy, image compression is needed to achieve these goals. In certain circumstances, visually lossy images may be diagnostically lossless; although image compression artifacts are detectable, their presence does not affect diagnostic performance (20). Several studies in which receiver operating characteristic analysis was used (21) have shown this to be true (22–24).

Although diagnostically lossless criteria would likely allow relatively high degrees of compression and substantial cost savings, the presence of perceivable artifact reduces acceptance among skeptical radiologists, and the validity of diagnoses based on lossy images in medicolegal proceedings is yet to be determined. In addition, receiver operating characteristic analyses are time-consuming and expensive and can usually be used to address only narrowly defined tasks. Multiple receiver operating characteristic studies would be required to provide results that cover a broad range of potential abnormalities with confidence. In light of this, we chose to concentrate on a more conservative criterion—namely, visually lossless compression for the full range of texture and density gradients in the image—in the belief that compressed images that are indistinguishable in any way from an original image are diagnostically lossless and would be readily acceptable even by skeptical radiologists.

The ICW proved to be a powerful tool for conducting observer studies. A large number of image sets could be evaluated efficiently. The alternating presentation of registered images at the ICW was intended to maximize viewer sensitivity to subtle image compression artifacts. Similarly, viewing distance was unconstrained, and images were magnified by a factor of two. Both of these latter factors should increase the conspicuity of subtle detail not visible when the region of interest occupied a smaller viewing angle. Results of previous studies (25,26) have shown decreases in detection of degradation due to image compression as viewing distance increases.

Display of images magnified by a factor of two also has clinical relevance, because most PACS stations have a "magnifying glass" tool. Radiologists may use this tool to evaluate isolated areas of the image at x2 magnification to detect subtle disease, particularly pneumothorax, fracture, and interstitial lung disease. We believe, therefore, that the use of magnification, close viewing distance, and flicker to exploit an observer's temporal sensitivity between image differences should result in a conservative and, we hope, widely accepted estimate of the visually lossless threshold.

We compared three methods for studying observer detection of image degradation. The two-alternative forced-choice and original-revealed forced-choice methods were similar. The difference was subtle but important. In the former method, when confronted with two original images or a visually lossless image, the observer was forced to guess, thus selecting the image that was compressed but indistinguishable from the original image 50% of the time. As the degradation became more apparent, selection of the compressed image decreased toward 0%. In the original-revealed forced-choice method, the observer would be expected to declare two original or visually lossless images to be equivalent 100% of the time. However, sometimes an original was judged to be degraded because the observer was intent on detecting the subtlest differences and may have "over read" the image. This was observed in our original-revealed forced-choice results, where observers declared the unaltered test image to be degraded 5% of the time and were thus operating at a low threshold for reporting degradation.

With the original-revealed forced-choice method, as the degradation became more apparent, judgment of the compressed image as equivalent to the original decreased toward 0%. Thus, the expected results ranged from 0% to 50% with the two-alternative forced-choice method and from 0% to 100% with the original-revealed forced-choice method. This has certain advantages for the display and analysis of the data. The patterns shown in the data suggest that observers detected degradation in the compressed images as frequently when using the original-revealed forced-choice method as they did with the two-alternative forced-choice method, which implies that the former technique is as sensitive as the latter. The original-revealed forced-choice experiment was conducted in less time by the observers and thus may have provided results more efficiently.

In contrast, an advantage of the two-alternative forced-choice method is that it can reveal trends in preference rather than just provide information about detection of differences. Of particular interest are the results for comparisons with images compressed at 8:1. For both JPEG and WTCQ, the 8:1 images were considered to be better than the original image 55%–65% of the time. Although this was a slight deviation from the expected chance result of 50% for visually lossless images, the trend was the opposite of that with all other levels of compression, where the compressed image was judged to be better less than 50% of the time. We hypothesize that low compression levels have the same effect as a low-pass filter, because the image is smoothed and the conspicuity of image noise is effectively decreased. Thus, the original-revealed forced-choice method was sensitive for detecting differences, but only with the two-alternative forced-choice method did the results reflect a preference for a test image over an original image.

Despite expectations for improved performance with wavelet-based algorithms, we found that the JPEG baseline algorithm resulted in performance that was as good as, if not better than, performance with the WTCQ algorithm implemented at low compression ratios. This is critical, because JPEG is a current standard that permits interoperability in a PACS environment. The data did suggest that WTCQ was better at very high compression ratios. These results are probably related to the way these two algorithms handle the data and the manner in which the artifact is manifested (ie, primarily as "tiling" or "blocking" with JPEG and as blurring with WTCQ).

Although radiographs of different body parts are likely to emphasize different compression artifacts, the chest radiograph demonstrates a broad range of structural and tonal characteristics that provide the opportunity to note degradation in soft tissues of uniform opacity and intricate trabecular and pulmonary parenchymal detail. Thus, although our study was limited to posteroanterior chest radiographs, we believe the results should be representative of other projection radiographs.

The resolution-metric method was intended to project the image characteristics of the compression algorithm onto a quantifiable dimension, thus providing a basis for comparison of various compression techniques. Observers reported being able to consistently select a reference image that matched the degradation in the compressed image, although at high compression ratios this was easier with WTCQ images than with JPEG images. We believe this is because the artifact introduced by the WTCQ algorithm is similar to the degradation introduced by blurring. At high compression ratios, it was more difficult to equate the tiling or blocking artifacts introduced by JPEG with blur artifacts introduced by WTCQ.

The use of spatial blurring by means of bandwidth limitation in the frequency domain proved to be a reasonable choice for a matching metric. Further exploration of degradation mechanisms for reference images might include different frequency filtering, variation of quantization levels, addition of random noise (both white noise and quantum mottle), or a combined blur-noise operation that follows a relationship similar to that of conventional x-ray detectors (ie, a speed-sharpness trade-off similar to that of screen-film or storage phosphor images).

This technique required more time than did the forced-choice methods but provided more information, particularly about the relative "performance" of algorithms at compression ratios above the visually lossless threshold. Such a comparison would be critical in a comparison of a new algorithm with an accepted one in the visually lossy range. In addition, we found that data from the resolution matching method could be used to estimate the visually lossless threshold by using linear regression. The results were nearly identical to those obtained with the two-alternative forced-choice and original-revealed forced-choice methods, which showed that the visually lossless threshold for the conservative viewing situation (superimposed images, x2 magnification, close viewing conditions) was greater than 10:1 for both algorithms, with JPEG images resulting in slightly better performance than WTCQ images. We also found this technique to be robust, with the number of data points and specific compression levels used having little effect on the predicted value.

The ICW is a versatile and powerful tool for comparative assessment of image quality. Sequential registered display of magnified images should help optimize observer sensitivity to differences and improve detection of subtle degradation, resulting in conservative estimates. The ICW monitor is a component of currently available commercial PACS systems, which makes translation of the results to a true clinical environment practical. These studies were conducted in the context of primary, rather than secondary, interpretation, and the methods were robust in that

they could be used with various equipment and acquisition, presentation, display, and viewing tasks.

The objective of our research was to establish a basis for acceptance of irreversible image compression for primary interpretation of diagnostic images. We believe that diagnostic loss can be avoided by using visually lossless levels of compression and that these compression levels are high enough to provide important time and cost savings and thus serve as a critical component for improved health care delivery in the PACS environment. Our results suggest that the JPEG baseline algorithm results in performance that is as good as that which results from a more complex wavelet-compression algorithm and that 10:1 image compression is visually lossless for most observers and is, therefore, acceptable for primary image interpretation without risk of affecting diagnosis. The composite results shown in Figures 4 and 5 demonstrate that most observers consistently detect image degradation at compression ratios of 21:1 and higher. This is supported by other researchers (27) who have suggested that 10:1 compression does not influence detection of subtle interstitial abnormalities but that important information may be lost at a ratio of 20:1, particularly when the images are interpreted by experienced thoracic radiologists.

Our research design, which used magnification, unrestricted viewing distance, and superimposition of registered images, was intended to produce a conservative estimate of acceptable image compression levels. Our hope is that comfort with visually lossless but mathematically degraded data sets will open the path for studies in a routine clinical environment, where less conservative constraints would support the use of more aggressive compression with its accompanying benefits. Future work is needed to address less stringent visually lossy but diagnostically lossless levels of compression by assessing diagnostic performance outcomes.

Acknowledgments

We are grateful to G. James Blaine, DSc, Jerome Cox, PhD, and R. Gilbert Jost, MD, at the Mallinckrodt Institute of Radiology, Washington University School of Medicine (St Louis, Mo), for their critical insight, thoughtful suggestions, and support in facilitating this collaborative investigation.

Footnotes

[2] **. Multiple body systems

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Abbreviations: ICW = image compression workstation JPEG = Joint Photographic Experts Group PACS = picture archiving and communication system WTCQ = wavelet-based trellis-coded quantization

Author contributions: Guarantor of integrity of entire study, R.M.S.; study concepts, B.R.W.,

E.M.; study design, E.M., D.H.F., S.S.Y., K.S.K.; definition of intellectual content, E.M., B.R.W., D.H.F.; literature research, R.M.S.; experimental studies, D.H.F., K.S.K., S.S.Y.; data acquisition, R.M.S., E.M., P.H., D.A.R., B.R.W.; data analysis, R.M.S., T.K.P.; statistical analysis, T.K.P.; manuscript preparation, R.M.S.; manuscript editing, D.D.H., R.M.S., B.R.W., E.M.; manuscript review, D.A.R., D.H.F.

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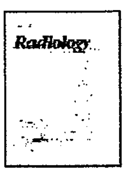

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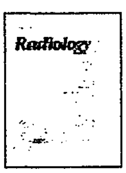

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EXHIBIT 18

US006542192B2

(12) **United States Patent**
Akiyama et al.

(10) **Patent No.: US 6,542,192 B2**
(45) **Date of Patent: Apr. 1, 2003**

(54) **IMAGE DISPLAY METHOD AND DIGITAL STILL CAMERA PROVIDING RAPID IMAGE DISPLAY BY DISPLAYING LOW RESOLUTION IMAGE FOLLOWED BY HIGH RESOLUTION IMAGE**

(75) Inventors: **Hideki Akiyama**, Fujisawa (JP); **Masaki Izumi**, Yokohama (JP)

(73) Assignee: **Eastman Kodak Company**, Rochester, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/949,845**

(22) Filed: **Oct. 14, 1997**

(65) **Prior Publication Data**

US 2001/0002142 A1 May 31, 2001

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(52) **U.S. Cl.** **348/333.11**; 348/222.1
(58) **Field of Search** 358/906, 909.1; 386/68, 109, 110, 112, 117, 120; 348/207, 220, 222, 231–233, 239, 333, 334, 552, 333.01, 333.05, 333.11, 333.12; 382/276, 298, 299, 305; 396/373, 374; H04N 5/225, 5/262, 5/222

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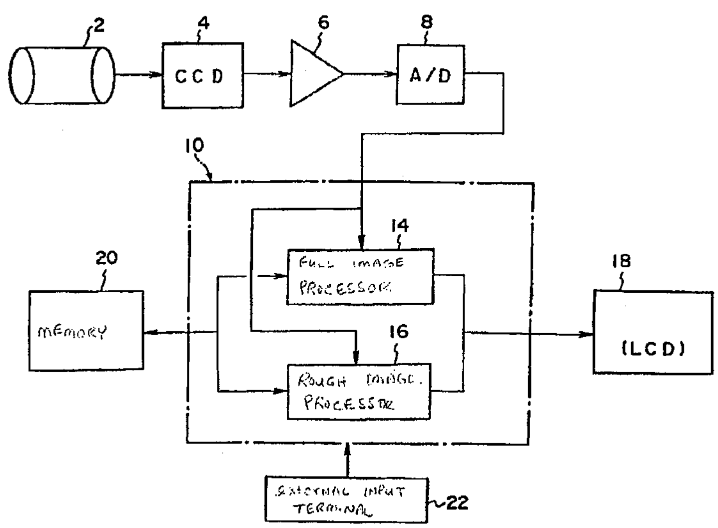
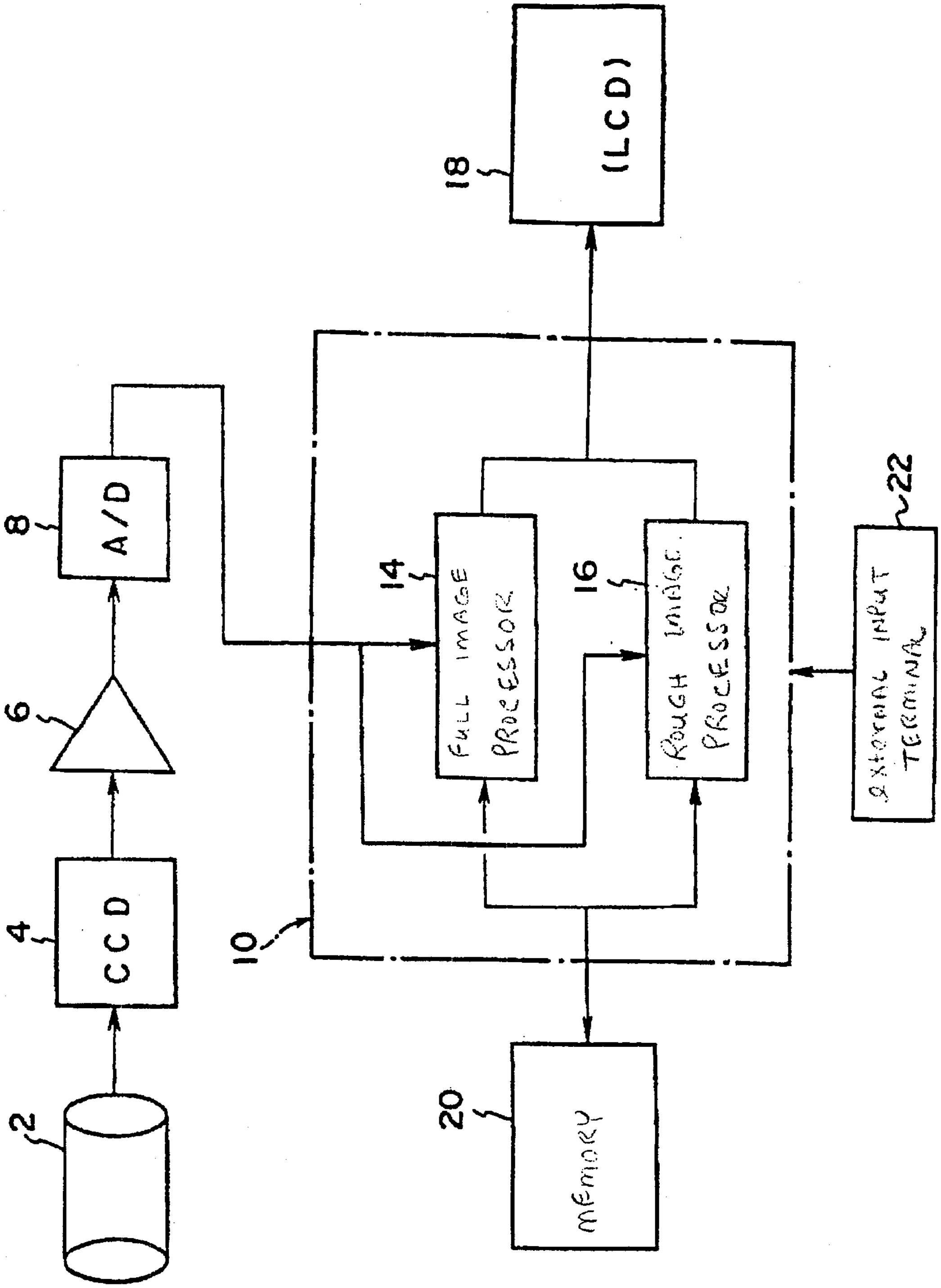
Primary Examiner—Ngoc-Yen Vu
(74) *Attorney, Agent, or Firm*—David M. Woods; Pamela R. Crocker

(57) **ABSTRACT**

A digital still camera comprises a full image processor and a rough image processor. The full image processor generates compressed full image data as primary image data, while the rough image processor generates non-compressed rough image data as secondary image data whose data volume has been reduced by limiting pixels thereof. In a reproduction mode, rough image data is read from a memory and subjected to display processing. A rough image is generated based on non-compressed rough image data with a short reproduction waiting time and displayed on an image display device. Thereafter, corresponding full image data is processed for display so that a relevant full image replaces the displayed rough image data, to be finally displayed.

17 Claims, 5 Drawing Sheets




CCD
A/D
(LCD)
FULL IMAGE PROCESSOR
ROUGH IMAGE PROCESSOR
EXTERNAL INPUT TERMINAL
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16
18
20
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FIG. 1

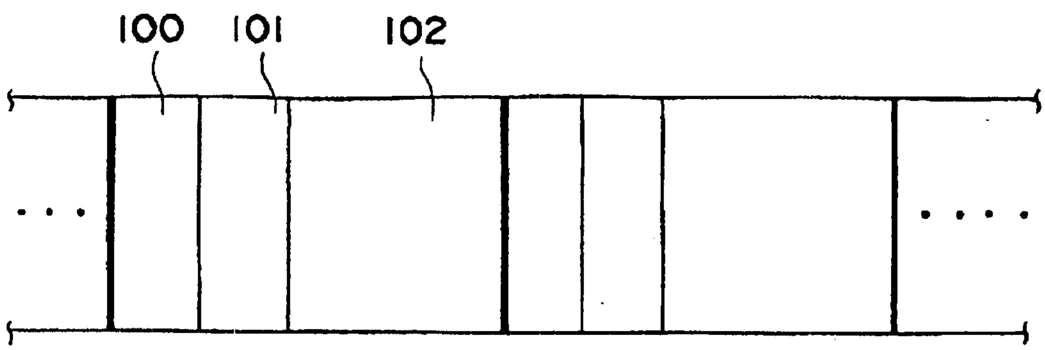

FIG. 2

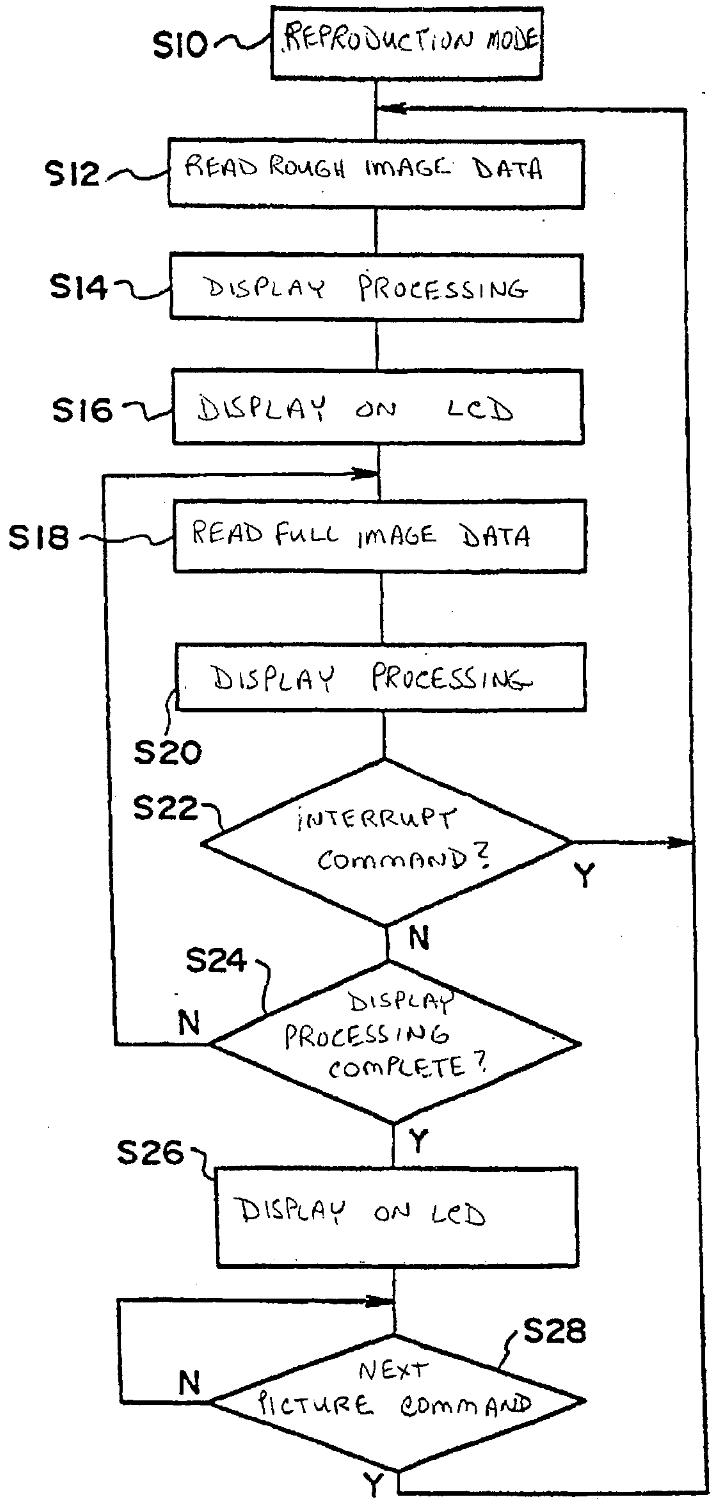
S10
REPRODUCTION MODE
S12
READ ROUGH IMAGE DATA
S14
DISPLAY PROCESSING
S16
DISPLAY ON LCD
S18
READ FULL IMAGE DATA
DISPLAY PROCESSING
S20
S22
INTERRUPT COMMAND?
Y
N
S24
DISPLAY PROCESSING COMPLETE?
N
Y
S26
DISPLAY ON LCD
S28
NEXT PICTURE COMMAND
N
Y

FIG. 3

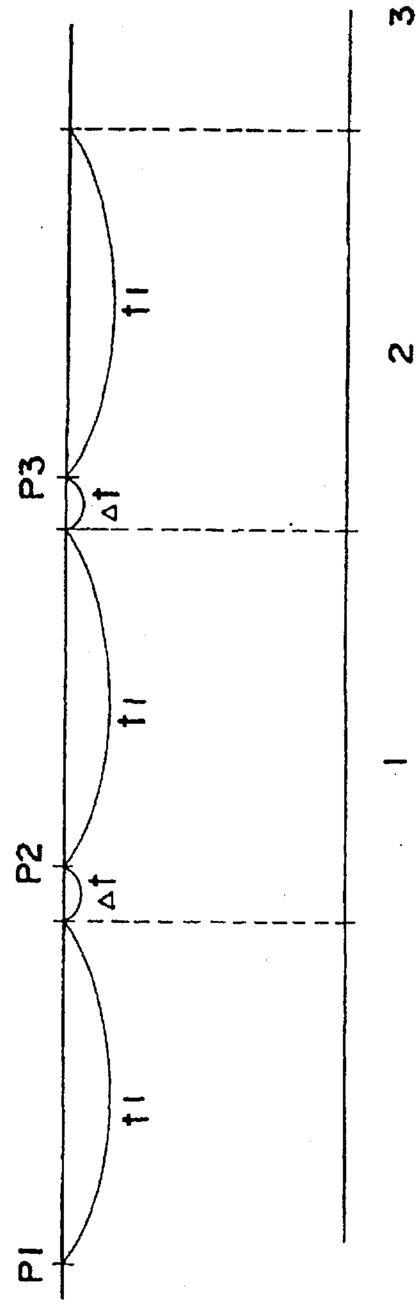

FIG. 4

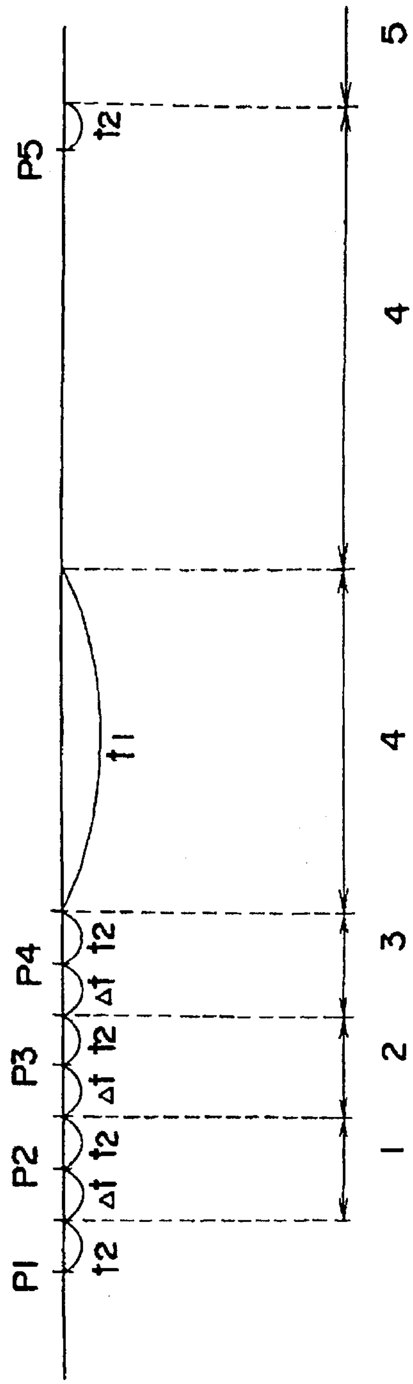

FIG. 5

IMAGE DISPLAY METHOD AND DIGITAL STILL CAMERA PROVIDING RAPID IMAGE DISPLAY BY DISPLAYING LOW RESOLUTION IMAGE FOLLOWED BY HIGH RESOLUTION IMAGE

FIELD OF THE INVENTION

The present invention relates to a digital still camera and, in particular, to a digital still camera which stores an image in the form of digital data as image data and performs display processing to the image data.

BACKGROUND OF THE INVENTION

A digital still camera which stores the image of an object in the form of digital data has been known. In such a camera, an image created using an optical system is converted into electric signals by optical-electric conversion elements, such as a CCD. The electric signals are converted into digital data, which is then subjected to predetermined compression processing before being stored in a memory incorporated into the camera.

Although an image photographed by a conventional camera of a film exposure type (a film exposure camera) cannot be seen until the film is developed, a photographed image by a digital still camera can be reproduced and displayed at any desired time by simply reading image data from a memory. This is advantageous and convenient for a digital still camera as it can perform operations which are impossible for a film exposure camera, including examination or erasure of photographed images.

For displaying reproduced images, a digital still camera is equipped with a display device, such as an LCD. After setting a camera in a reproduction mode, a user presses a reproduction button on the camera body, and display processing is performed to image data for one picture. Display processing specifically includes image data reading from a memory, compressed data expansion, color correction, picture size changing, and so forth. Color correction is correction with respect to discrepancies between color data for images outputted from a CCD and those to be inputted into a display device, such as an LCD. With picture size changing, the size of a picture, which is expressed by the number of pixels whose data is contained in image data for one picture (i.e., the number of horizontal pixels×that of vertical pixels), is changed so as to fit the size of a display screen. After display processing as above, an image is displayed on a display device.

As described above, image data is subjected to display processing in response to a user command inputted for display, and a corresponding image is subsequently reproduced and displayed. The period of time between command inputting and image displaying is referred to as a reproduction waiting time, during the majority of which compressed image data is being expanded. Therefore, a high speed expansion could reduce a reproduction waiting time, which is, however, subject to limitation. In a conventional reproduction method, it has taken as long as approximately a few seconds to display a reproduced image due to a long reproduction waiting time. This forces a user to wait for a few seconds after pressing a reproduction button before having a reproduced image displayed. It has thus been long desired to reduce a reproduction waiting time to the level where a reproduced image is displayed almost simultaneously upon operation of a reproduction button by a user.

A digital still camera is further advantageously able to store a larger number of pictures than a film exposure

camera. A user searching for a particular picture from among many pictures of photographed images, displays all the pictures sequentially. To be specific, the user presses a reproduction button to display one picture, and if that is not the one he wants, he again presses the button to have another picture displayed. He has to repeat this process until a desired picture appears. In this manner of searching, it takes a long time for a user to find one desired picture from among many pictures when a reproduction waiting time for one picture is long and a whole time necessary to display each picture is inevitably prolonged. With this in mind, it has also been desired to reduce a period of time necessary to display pictures for review.

SUMMARY OF THE INVENTION

The present invention has been conceived to overcome the above problems, and aims to produce a digital still camera in which a reproduced image can be promptly displayed with a reduced reproduction waiting time. The present invention also aims to provide an image reproduction and display method to be employed by a digital still camera which achieves the above object.

(1) In order to achieve the above object, according to the present invention, there is provided a digital still camera having a reproduction function for displaying an image on a display after processing image data stored inside thereof for display, comprising a memory storing image data including primary image data and secondary image data, the secondary image data requiring a shorter time for display processing than the primary image data; a primary image display processor performing display processing on the primary image data; a secondary image display processor performing display processing on the secondary image data; and a display replacer for replacing display images from a secondary image to a primary image after completion of display processing on the primary image data, the secondary image having been displayed in a reproduction mode prior to the primary image.

According to another aspect, there is provided a reproduction and display method adopted by a digital still camera for displaying an image on a display after processing image data stored inside thereof for display, comprising steps of: performing primary image display processing to primary image data; performing secondary image display processing to secondary image data, the secondary image data requiring a shorter time for display processing than the primary image data; and replacing display images from a secondary image to a primary image after completion of display processing on the primary image data, the secondary image having been displayed.

It should be noted that primary image data is used to obtain a normal photographed image, and preferably allows accurate reproduction of an originally photographed image with high image quality. Primary image data may be either non-compressed data or compressed data which has been compressed using a predetermined compression method.

Secondary image data can be processed for display in a shorter period of time than primary image data. High image quality, such as resolution, is not required for secondary image data, as reproduction of an image which is clear enough to distinguish a photographed object is the aim of the secondary image data.

For instance, secondary image data is image data whose data volume has been curtailed to an extent that a reproduced image based thereon is still capable of distinguishing a photographed object. Preferably, secondary image data may

be non-compressed data with the data volume reduced, for instance, in sampling processing in which some pixel data are removed, as non-compressed data can be processed for display in a significantly shorter period to time compared to compressed data. Alternatively, compressed data having a reduced data volume may be employed since data having a smaller volume will be processed in a shorter time.

The present invention has been conceived in view of the following facts. Image reproduction based solely on primary image data achieves high quality images but needs a longer reproduction waiting time, whereas image reproduction based solely on secondary image data achieves reduction of a reproduction waiting time but reproduces images with only poor quality. That is, it is difficult to reproduce an image with high quality in a shorter reproduction waiting time based solely on image data of either one of the above two types. In view of the above, this invention is constructed to utilize advantages of image data of both types.

According to this invention, a secondary image picture is first displayed in a reproduction mode and, after completion of display processing for primary image data, the secondary image picture being displayed is replaced by a corresponding primary image picture. Since display processing for secondary image data is short, secondary image pictures can be displayed with only a short reproduction waiting time. The secondary image picture being displayed is automatically replaced by a primary image picture, as mentioned above. With this arrangement, a user barely has to wait until an image is displayed, and he can know the details of a photographed image by examining a primary image picture. The present invention therefore enables both reduction of a reproduction waiting time and displaying of a high quality image. This can increase the product value of a digital still camera.

(2) According to another aspect, in the reproduction and display method as defined above, display processing of primary image data corresponding to a secondary image which is then being displayed is stopped when a predetermined command is externally inputted; and another secondary image is displayed.

According to this aspect, the present invention is quite beneficial for a user who searches a desired picture from among many photographed images by sequentially displaying them. Specifically, a secondary image picture is displayed as soon as a user inputs a command, so that the user reviews it to check an object shown thereon as to whether or not the picture shown is his desired one. If it is not the picture he wants, he inputs another display command. In response to this command, ongoing display processing for a corresponding primary image data is halted and image data for the next secondary image picture is subjected to display processing so that the next secondary image picture is displayed. When the user finds a desired secondary image after repetition of the above process, he stops advancing pictures so that display processing for corresponding primary image data continues to completion. Then, the secondary image picture being displayed is automatically replaced by a relevant primary image picture, so that the user can examine the details of the photographed image by referring to the primary image. As described above, the present invention achieves significant reduction of a period of time necessary for a user to search for a desired photographed image and to examine the details thereof.

(3) In some conventional digital still cameras, non-compressed index image data, such as thumbnail image data, is stored separately from compressed image data. When the present invention is applied to such cameras, index image data may also be used as secondary image data. In such use, display processing for secondary image data may include processing to change the size of index display image data.

Index image data is inherently used for displaying a plurality of pictures simultaneously on a display device when image data is processed by a computer, and suchlike. In this use, high image quality is not absolutely required as each picture is only displayed in a small size, and there is more demand for a shorter processing time before a plurality of pictures are simultaneously displayed. Thus, index image data is generated in sub-sampling processing in which pixel data of original image data is removed, so as to have a smaller data volume. For instance, the data volume of primary image data is a few hundred Kbytes, while that of index image data is 1/10 thereof or else.

Index image data is usable only to generate a rough image picture which at most distinguishes an image shown thereon, and its resolution is too low to clearly present details or photographed conditions of the image. Index image data hardly allows reproduction of high quality image which is necessary for thorough examination of details. However, it advantageously allows display of an image in a short time as it is non-compressed and has a small data volume. Index image data is therefore preferably used as secondary image data of this invention.

When index display image data is used also as secondary image data unique to the present invention, it is unnecessary to generate image data of another type which has not been conventionally used or to secure memory area for storing such image data within a memory.

It should be noted that the object of this invention can also be achieved by using non-compressed image data which allows reproduction of an image with suitable resolution for the image display device of a camera, stored for use solely in a reproduction mode. With this structure, replacement of a secondary image picture by a primary image picture is unnecessary. However, such image data must have decent resolution, and therefore a relatively large data volume is inevitable so as to match a display device. Even worse, since memory area must be secured for those data, which has a large volume, the number of pictures whose data can be stored in the memory is accordingly reduced. This is contrary to one of the advantages of a digital still camera, i.e., capability to store numerous pictures, and thus not preferable. On the contrary, in this invention, the number of pictures whose data can be stored is not adversely affected as above when secondary image data, having a small data volume, is stored together with primary image data.

(4) In this invention, a memory may be either of a detachable type, like a detachable memory card, or a non-detachable type with respect to a camera. A flash memory is often used for the memory. Alternatively, any other medium accessible in an electric, magnetic, or optical method may be applied, such as a semiconductor memory, an IC card, a magnetic disc, RAM, and a magnetic tape.

Also, primary image data and secondary image data may be stored in the same memory or different memories. Memory areas for primary and secondary image data may be arranged as desired.

Display processing for secondary image data may be performed prior to that for primary image data, or both may be performed in parallel.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features, and advantages, will become further apparent from the following description

of the preferred embodiment taken in conjunction with the accompanying drawings wherein:

FIG. **1** is a block diagram showing the structure of a digital camera according to a preferred embodiment of the present innovation;

FIG. **2** is a diagram explaining a memory area of a memory of the camera shown in FIG. **1**;

FIG. **3** is a flowchart for an operation of a camera according to the preferred embodiment of this present invention in a reproduction mode;

FIG. **4** is a time chart for a reproduction operation by a conventional camera; and

FIG. **5** is a time chart for a reproduction operation by a camera according to the preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

In the following, a preferred embodiment of the present invention will be described referring to the accompanying drawings.

FIG. **1** is a diagram showing the structure of a digital still camera according to a preferred embodiment of this invention. An optical system **2** comprises a lens, a shutter, and so on, and forms an image of an object on image elements of a CCD **4**. In the CCD **4**, image information is converted into an analogue signal. The analogue signal is amplified by an amplifier **6** and then converted into a digital signal by an A/D converter **8** before being supplied as an image input to a controller **10**. Note that an image input comprises pixel data representing colors of respective pixels.

In addition to various image processing (described later), the controller **10** controls the entire operations of the camera. It performs pre-processing of an image input supplied, including noise removal, white balance adjustment, and gamma adjustment, before outputting the image input into a full image processor **14** and a rough image processor **16**. Pre-processing may be performed by means of hardware provided upstream of the A/D converter **8** or by respective image processors.

The full image processor **14** performs image processing including image compression and expansion. For compression, the JPEG method, an international standard method for compressing still image data, or other methods may be employed.

An image input is encoded via compression here into full image data, or primary data, which is used as normal image recording data. Full image data allows reproduction of vivid images.

In addition to the above, the full image processor **14** performs display processing of full image data which has been read from a memory **20** to the controller **10**. Display processing includes data expansion for decoding, color correction (mentioned above), picture size changing, and so on. With picture size changing, pixel data of image data is limited so as to fit to the size of the screen of a digital still camera which is generally small and thus includes a smaller number of vertical and horizontal pixels. Note that display processing also includes various processing other than the above, such as data reading from a memory or transmitting to a display by the controller **10**.

Data compression and expansion may also be performed by a dedicated IC which is, for instance, externally provided to the controller **10** as a part of the full image processor **14**. For generation of full image data, the controller **10** changes

color data of image data from RGB to YCC and outputs the image data to the IC for compression. For display processing, on the contrary, the IC expands compressed data and supplies it to the controller **10** for other processing.

In the rough image processor **16**, different from the full image processor **14**, data compression/expansion is not performed. Instead, sub-sampling processing is carried out to limit pixel data of an image input, thereby generating rough image data, or secondary data. Rough image data is generated so as to meet such a requirement that an image created based thereon be clear enough to distinguish an object, and thus does not require high image quality. Therefore, a drop in resolution at the time of reproduction is not a problem for rough image data. That is, rough image data can be rephrases as data generated by limiting data volume in view of the above.

In this embodiment, the volume of rough image data is suppressed to be, for instance, about 10 Kbytes. This is less than 1/10 of the volume of full image data for a present digital still camera, which is, for instance, about 100 Kbytes. As a result of limiting, the size of a picture relative to rough image data is smaller than that of a camera screen (i.e., the numbers of vertical and horizontal pixels).

As described above, it has been known to record index image data, such as thumbnail image, separately from full image data. Some index image data is non-compressed and has a significantly reduced data volume due to limiting. Such index image data meets the aforementioned requirement for rough image data of this embodiment, and thus can also be used as rough image data in this embodiment.

In addition to the above, the rough image processor **16** performs display processing to rough image data which has been read from the memory **20** to the controller **10**. Display processing mainly includes color correction (mentioned above) and picture size changing. Picture size changing here requires interpolation of pixel data. As it is smaller than a camera screen, a picture relative to rough image data should be given extra pixel data by interpolation so as to match the size of the image display device **18**.

The controller **10** is connected to the memory **20** and the image display device **18**. The memory **20** comprises a flash memory for storing full image data generated by the full image processor **14** and rough image data generated by the rough image processor **16**. FIG. **2** depicts memory areas of the memory **20**. In the memory **20**, a header area **100**, a rough image area **101**, and full image area **102** are set for every photographed image. In a header area **100**, various information regarding a photographed image, such as an image frame number, is recorded. In the rough image area **101** and full image area **102**, rough image data and full image data are respectively recorded. A rough image area **101** is smaller than a full image area **102** as rough image data has a significantly smaller volume than full image data.

After display processing either by the full image processor **14** or the rough image processor **16**, the controller **10** supplies image information to the image display device **18** which comprises an LCD for a display screen. The image display device **18** then converts the image information supplied into a video signal to display it on the LCD.

The controller **10** is further connected to an external input terminal **22**. When a user instructs various operations with commands using operation buttons on the camera body, these commands are inputted via the external input terminal **22** to the controller **10**. User command includes (1) "switching between a shooting mode and a reproduction mode," and (2) "displaying the next picture." A "displaying the next

picture" command is a command for displaying a picture having an image frame number larger by one than that for the picture being displayed, and a backward command for a picture having an image frame number smaller by one.

The controller **10** is constructed so as to be connectable to an external display or computer. With these connected, the controller **10** supplies data which has been read from the memory **20** to these external devices.

Next, an operation of a camera according to this embodiment in a shooting mode will be described. With a shooting mode set, the image of an object is displayed on the image display device **18**. Looking at either the image display device **18** or a finder (not shown), the user directs the camera at a desired object. The brightness of the object is detected using outputs of light receiving elements (not shown), so that an exposure time and an aperture value for the shutter of the optical system **2** are accordingly determined. The shutter is opened/closed by using a shutter button (not shown) so that the image of the object is exposed on the CCD **4**. The CCD **4** outputs a signal, which is amplified by the amplifier **6** and then converted into a digital signal by the A/D converter **8** before being inputted as an image input into the controller **10**.

In the controller **10**, the predetermined pre-processing mentioned above is performed. The full image processor **14** and the rough image processor **16** generate full image data and rough image data, respectively, based on an image input supplied. Subsequently, both data are transmitted from the controller **10** to the memory **20** to be stored therein along with header information.

Referred to FIG. **3**, the operation of a camera according to this embodiment in a reproduction mode will be described. When a user command for mode switching from a shooting mode to a reproduction mode is inputted into the controller **10**, so that a reproduction mode is set (**S10**). In the camera of this embodiment, a picture last shot in the shooting mode is set to be initially displayed in the reproduction mode. Thus, after a reproduction mode was set, processing after step **S10** is performed to image data for a picture having the largest image frame number.

Specifically, rough image data is read from the memory **20** (**S12**) and subjected to display processing in the rough image processor **16** (**S14**). Display processing here mainly includes color correction and picture size changing. Here, interpolation is applied to change the size of a relevant picture to have it match in size the LCD of the image display device **18**, as mentioned above. As it is not subjected to JPEG compression, rough image data can be used intact as display data only with the picture size changed. Display processing at step **S14** therefore can be completed in a minimum time. Image data subjected to display processing is then supplied to the image display device **18** so that a relevant image is displayed on the LCD (**S16**).

Upon completion of display processing for rough image data, the controller **10** reads full image data with the same image frame number as that of the rough image data being displayed from the memory **20** (**S18**), so that the full image processor **14** performs display processing to the full image data (**S20**). Display processing here includes, as described above, data expansion for decoding, color correction, and picture size changing. The picture size is reduced here as a picture relevant to full image data is larger than the display screen. Since display processing for full image data includes expansion, it takes some time.

In this embodiment, reading and display processing for rough image data for one picture is performed at once at steps **S12** and **S14**, respectively, whereas those for full image data for one image is performed at once at steps **S12** and **S14**, respectively, whereas those for full image data for one image is performed over several divided stages. This difference in processing methods for rough and full image data is attributable to the difference in the nature of respective image data.

In the steps **S18** and **S20**, the first stage of the several divided processing stages for full image data is performed. With the first stage completed at step **S20**, the control **10** then judges whether or not a user's interruption command for displaying the next image picture has been inputted via the external input terminal **22** (**S22**). Although the command is either a forward command or a backward command as mentioned above, at this stage, where the last shot picture has been processed for display, only a backward command is to be received. If a next picture display command is received at step **S22**, the ongoing display processing with respect to full image data is disconnected, so that the operation flow returns to step **S10** to start identical processing to the above with respect to the next picture.

On the other hand, if no interrupt command is received at step **S22**, whether or not display processing for full image data has been completed is detected (**S24**). If uncompleted, the operation flow returns to step **S18** to continue reading and display processing for full image data so that the next stage of the several remaining divided display processing stages for the full image data is performed.

When display processing for full image data completes at step **S24**, the data is supplied to the image display device **18** so that a corresponding picture is displayed on the LCD (**S26**). In displaying, the rough image picture being displayed is replaced by a full image picture. In replacing, the rough image pictures is overwritten by a corresponding full image picture from left to right and upper to lower of the LCD for every partial band area having a predetermined width. With this manner of replacement, the picture on the display is smoothly shifted while avoiding abrupt changing or momentary disappearance of a displayed picture. Thus, the user does not feel a sense of incongruity. It should be noted that a picture may be overwritten not only from upper to lower and left to right, as above, but also diagonally. The width of a band area for sequential overwriting may be desirably set, such as the width for one scan line.

When the above picture switching has been completed, input of a user command for displaying the next picture is again awaited, similar to step **S22**. Specifically, whether or not a next picture display command has been inputted is judged (**S28**). This judgment will be repeatedly made until issuance of a command is detected. Until this detection, the full image picture remains displayed. With a command detected, the operation flow returns to step **S12** where identical processing to the above is carried out to image data for a picture with the next image frame number.

Next, an operation of a camera according to this embodiment with a computer externally connected thereto will be described. The controller **10** reads recorded data from the memory **20** and supplies it to the computer. The computer performs display processing to a plurality of rough image data supplied. It then divides the display screen into a plurality of regions to display each rough image picture for every region. With this arrangement, a user is able to review a plurality of photographed images at the same time. In this manner, rough image data is also used as index image data which is applied when using external devices, such as a computer.

By the way, a user utilizes reproduction display function to display images so as to review photographed images. Specifically, a user sequentially displays a plurality of images one by one using a forwarding or backwarding operation. For review, a user may take sufficient time to examine each image or moves on without spending much time on each. This reproduction operation will next be described using a comparison between a conventional camera and a camera of this invention. In the following description, it is assumed that a user searches for one particular image from among many images.

FIG. **4** is a timing chart for a reproduction operation by a conventional camera. When a user sets a reproduction mode (P1), the last shot picture is initially displayed. With a conventional camera, only full image pictures are displayed. That is, the first full image picture is displayed after a reproduction awaiting time, namely, t1, from setting the mode (P1), wherein t1 is relatively long such as a few seconds.

If this picture is not the one the user wants, he or she inputs a next picture display command (backwarding) P2. This judgment by the user takes Dt. Subsequently, the second full image picture is displayed after a reproduction waiting time t1 from input of the command P2. This whole process has to be repeated until the user finds his desired picture. Since it takes a long time to display one picture to review it with a conventional camera, the entire period of time spent before a desired image is found is inevitably prolonged.

FIG. **5** is a timing chart for a reproduction operation by a camera of this embodiment. When a user sets a reproduction mode (P1), the last shot picture is initially displayed. According to the flowchart shown in FIG. **3**, a rough image is initially displayed (**S16** in FIG. **3**), in which a reproduction waiting time t2 is significantly shorter than that t1 for a full image picture, for instance, being 1/10 of the latter.

Although a rough image picture, having only low resolution, is not clear enough to present details and conditions of photographed images, it is still clear enough to distinguish an object shown. If the full image picture initially displayed is not the one the user wants, he or she inputs a next picture display command (backwarding) P2. This judgment by the user takes Dt, similar to the process shown in FIG. **4**. In response to the command **P2**, display processing ongoing to full image data is disconnected, as shown in S22 in FIG. **3**, and display processing for the second rough image picture is started instead so as to display a corresponding picture. A reproduction waiting time here is t**2**.

This whole process will be repeated until the user finds his desired image. Assume that the fourth picture from the last shot one is the picture he wants. The user stops advancing pictures when the fourth rough image picture is displayed. Then, display processing for full image data for a corresponding image is continued to be completed. After a reproduction waiting time t**1**, the rough image picture on display is replaced by a corresponding full image picture. With a full image picture displayed, the user can examine the photographic condition of the image. Thereafter, if the user inputs a next picture display command p**5**, the fifth rough image will then appear.

As described above, according to this embodiment, a period to time from input of a user's instruction to display a picture to displaying of the picture concerned, is significantly reduced, so that the user scarcely has to wait until a picture is displayed. Moreover, the user is able to examine the details of a photographed object by examining a full image picture displayed. Further, a period of time necessary for a user to reproduce and examine photographed images one by one is significantly reduced. Thanks to these advantages, a digital still camera according to this embodiment has higher product value.

Also, since index image data is used also as rough image data in the above, the present invention can be achieved without including either a structure for generating rough image data in a controller **10** or a memory area for storing rough image data in the memory **20**.

Although the last shot picture is initially displayed in the above, any desired photographed picture, for instance, the initially shot picture, may be set for an initial display.

Further, display processing for rough image data and for full image data may be performed in parallel, instead of serially as above in the flowchart in FIG. **3**.

While there have been described what are at present considered to be preferred embodiments of the invention, it will be understood that various modifications may be made thereto, and it is intended that the appended claims cover all such modifications as fall within the true spirit and scope of the invention.

PARTS LIST

FIG. **1**
2 optical system
6 amplifier
14 full image processor
16 rough image processor
18 display
20 memory
22 external input terminal
FIG. **2**
100 header
101 rough image
102 full image
FIG. **3**
S10 set reproduction mode
S12 read rough image data
S14 display process for rough image
S16 display rough image
S18 read full image data
S20 display process for full image
S22 next picture display instructed ?
S24 display process for full image completed?
S26 display full image by replacement
S28 next image display instructed ?
FIG. **4**
user operation
display image
full image **1**, **2**, **3**
FIG. **5**
Rough image **1**, **2** . . .

What is claimed is:

1. A method for using a digital camera to capture and display images on an image display device of the digital camera, comprising the steps of:

(a) capturing a plurality of images;

(b) storing in a memory, primary image data and secondary image data, the primary image data providing accurate reproduction of the captured image, and the secondary image data providing an index image which can be used by an external device to display the plurality of images in a corresponding plurality of regions on a display screen of the external device;

(c) retrieving the secondary image data from the memory for a first image;

(d) processing the secondary image data for the first image to produce a processed secondary image having additional pixel data;

(e) displaying the processed secondary image on the image display device;

(f) retrieving the primary image data from the memory for the first image;

(g) processing the primary image data for the first image to produce a processed primary image having a reduced picture size; and

(h) replacing the display of the processed secondary image for the first image on the image display device with a display of the processed primary image for the first image automatically after the completion of step (g).

2. The method according to claim **1** further including the steps of:

(i) stopping step (g) when a predetermined command is externally inputted;

(j) retrieving the secondary image data from the memory for a second image;

(k) processing the secondary image data for the second image to produce a processed secondary image having additional pixel data; and

(l) displaying the processed secondary image for the second image on the image display device.

3. The method according to claim **1** wherein step (h) includes overwriting the processed secondary image for the first image with the processed primary image for the first image using partial band areas having a predetermined width.

4. The method according to claim **1** wherein the first image is the last captured image of the plurality of captured images.

5. The method according to claim **1** wherein the processing in steps (d) and (g) is performed in parallel.

6. The method according to claim **1** wherein the size of the processed secondary image produced in step (d) matches the size of the image display device.

7. The method according to claim **1** wherein step (d) includes interpolating the secondary image data so that the size of the processed secondary image matches the size of the image display device.

8. The method according to claim **7** wherein step (g) is performed over a plurality of divided stages.

9. The method according to claim **1** wherein the memory is a detachable memory card.

10. A method for using a digital camera to capture and display images on an image display device of the digital camera, comprising the steps of:

(a) capturing a plurality of images;

(b) storing in a memory, primary image data and secondary image data, the primary image data providing accurate reproduction of the captured image, and the secondary image data providing an index image which can be used by an external device to display the plurality of images in a corresponding plurality of regions on a display screen of the external device;

(c) retrieving the secondary image data from the memory for a first image;

(d) processing the secondary image data for the first image to produce a processed secondary image having additional pixel data;

(e) displaying the processed secondary image on the image display device;

(f) retrieving the primary image data from the memory for the first image;

(g) initiating processing of the primary image data for the first image to produce a processed primary image having a reduced picture size;

(h) stopping step (g) when a predetermined command is externally inputted;

(i) retrieving the secondary image data from the memory for a second image;

(j) processing the secondary image data for the second image to produce a processed secondary image having additional pixel data;

(k) displaying the processed secondary image for the second image on the image display device;

(l) processing the primary image data for the second image to produce a processed primary image having a reduced picture size; and

(m) replacing the display of the processed secondary image for the second image on the image display device with a display of the processed primary image for the second image automatically after the completion of step (l).

11. The method according to claim **10** wherein step (m) includes overwriting the processed secondary image for the second image with the processed primary image for the second image using partial band areas having a predetermined width.

12. The method according to claim **10** wherein the first image is the last captured image of the plurality of captured images.

13. The method according to claim **10** wherein the processing in steps (d) and (g) is performed in parallel, and the processing in steps (j) and (l) is performed in parallel.

14. The method according to claim **10** wherein the size of the processed secondary image produced in step (d) matches the size of the image display device.

15. The method according to claim **10** wherein step (d) includes interpolating the secondary image data so that the size of the processed secondary image matches the size of the image display device.

16. The method according to claim **15** wherein step (g) is performed over a plurality of divided stages.

17. The method according to claim **10** wherein the memory is a detachable memory card.

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